Up-tapered fiber Mach-Zehnder interferometer fabricated by using a fusion splicer*

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An up-tapered Mach-Zehnder interferometer (MZI) is proposed and demonstrated. By applying a modification setting of an existing program of the fusion splicer, two up-tapers are fabricated by pushing both sides of the fiber to the middle. It is found that the maximum extinction ratio reaches up to 20 dB. With the fiber length of 6.3–49 cm between the two up-tapers, the free spectral range (FSR) changes from 10.7 nm to 1.3 nm. Besides, the wavelength of maximum extinction ratio shifts to the shorter wavelength in the scope of tens of nanometers, while the elongation changes from 0% to 0.23%.

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Mach-Zehnder interferometer (MZI) based on optical fiber has been used in many fields, such as fiber laser[1], filter[2-4] and sensor[5-7]. A typical MZI contains an optical splitter, a beam combiner and two asymmetric arms. Normally, the optical splitter and beam combiner of MZI have the same configuration of tapers, but with opposite direction of the beam. Two tapers, at a certain distance away from each other, are pulled on a single fiber to make the MZI. The beam is divided into two branches, which both come to the first taper. One still travels in the core of the fiber, while the other travels in the cladding. The second taper combines the two branches of beams into the core. Account for the different refractive indices (RIs) of the core and cladding of the fiber, a relative phase difference (RPD) is induced between the core and cladding modes. The relative phase difference of the two branches of beams results in an interference pattern at the output of the second taper. Just because of this characteristic of the MZI based on two tapers, it is used as a comb filter. However, due to the slender tapers[7], the strength of the MZI gets worse.

In this paper, an MZI based on two up-tapers is fabricated by using a fusion splicer. The parameters are modified on the basis of the inherent program of pulling tapers. All steps of pulling are turned off, and the fusion times are appropriatly increased. While the program is going, both sides of the fiber are pushed simultaneously to the middle.

Fig.1 shows the schematic diagram of the proposed MZI based on two up-tapers, where L_1 is the length of the single mode fiber (SMF) between the two up-tapers, and L_2 is the length of each up-taper. D_1 and D_2 indicate the diameters of the SMF and the up-tapers, respectively. The arrows show the propagation of the beams. When the beam comes to the first up-taper, it is divided into two branches, one still travels in the core, while the other one travels in the cladding of the SMF. Here, the first up-taper is regarded as an optical splitter. While the two parts of beams travel to the second up-taper, they are combined in the core. In a similar way, the second up-taper works as a beam combiner. Due to the different RIs between the core and cladding, the optical path difference (OPD) of the two branches of beams is shown as[8-10]

$$\Delta L = \left(n_{\mathrm{eff1}} - n_{\mathrm{eff2}}\right) \cdot L_1 , \tag{1}$$

where n_{eff1} and n_{eff2} are the RIs of the core and cladding of the SMF, respectively. Then the RPD between two branches of beams which travel in the core and cladding of the SMF between the two up-tapers is dedicated by[10]

$$\psi = 2\pi \cdot \Delta L / \lambda , \tag{2}$$

where λ indicates the input wavelength in vacuum. With the increase of the length of the SMF between the two up-tapers, the space between the adjacent peak wavelengths is narrower and narrower. The space is indicated by the free spectral range (FSR), and has the following form[10]

$$FSR = \lambda^2 / \Delta L . \tag{3}$$

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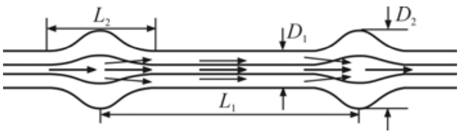


Fig.1 The schematic diagram of the proposed MZI based on two up-tapers

An existing program of fusion splicer (FSU975, ERICSSON) with a proper modification is used to fabricate the two up-tapers. The parameters which need to be altered are shown in Tab.1. The overlap of 49.9 μm, which reaches the maximum, is still not enough to fabricate an available up-taper in a single operation. To get a bigger up-taper, it is required that both sides of the SMF-28 should be pushed to the middle while the fusion splicer works. Fig.2 shows an optical graph of the up-taper.

Tab.1 The altered parameters to fabricate the two up-tapers

Parameter	Value
Pull 1	No
Pull 2	No
Pull 3	No
Overlap (μm)	49.9
Fusion time 1 (s)	20.0
Fusion current 1 (mA)	15.5
Fusion time 2 (s)	8.0
Fusion current 2 (mA)	13.0
Fusion time 2 (s)	3.0
Fusion current 2 (mA)	6.0

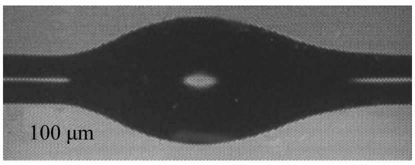


Fig.2 Optical micrograph of the up-taper

The diameter and length of the up-taper in Fig.2 are indicated as D_2=327 μm and L_2=744 μm. The size of the other up-taper of the MZI is almost the same. When the fusion splicer works, because of the different overlaps of SMF-28, the diameters and lengths of the up-tapers have different values. A larger overlap leads to a bigger up-taper.

Fig.3 shows the transmission spectrum of an MZI with L_1=46.3 cm. The FSR is about 1.3 nm, and the maximum of extinction ratio is more than 17.5 dB. The loss of the MZI is approximately 15 dB. It is the same as the MZI based on traditional tapers, and the FSR of the MZI is related with L_1. Different L_1 values result in different FSRs, which can be found in Fig.4(a)–(c). With the decrease of L_1, the FSR increases as inverse proportion, and it can be found from Fig.4(d). Then we draw the MZI with a tunable device shown in Fig.5. The distance between the two holders of the device is 17.2 cm, and L_1 is equal to 13.1 cm. The MZI with two up-tapers on a SMF-28 is placed between the two holders. Elongation is adjusted by rotating the micrometer on the right side (or on the left side).

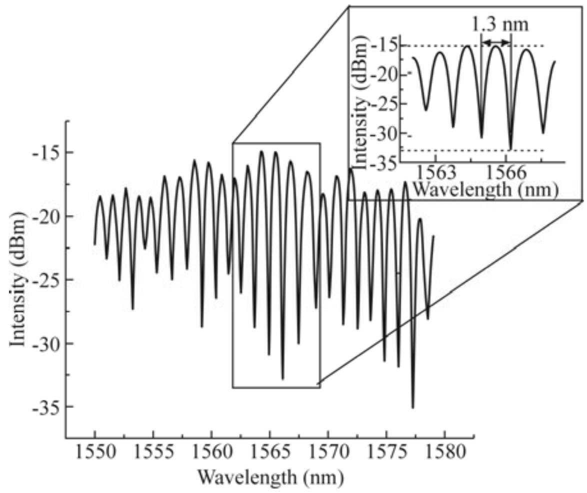
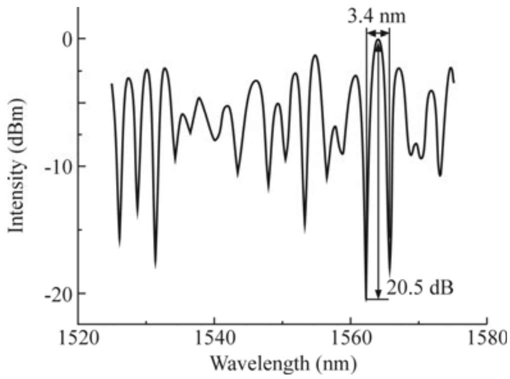
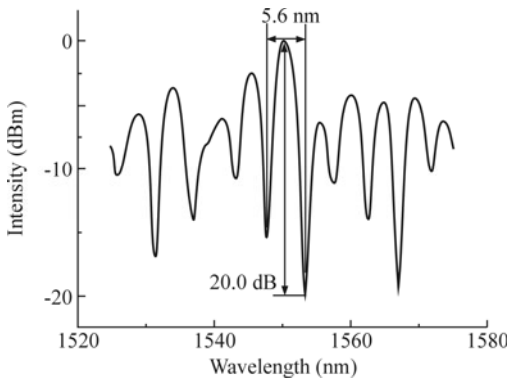


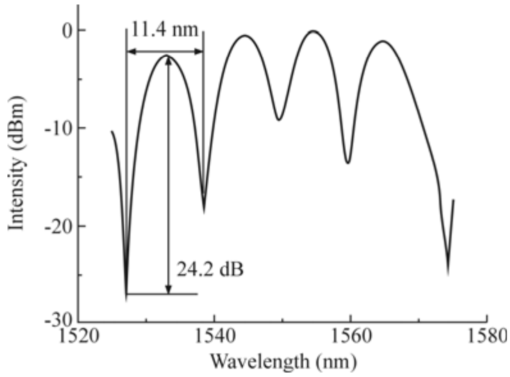
Fig.3 The transmission spectrum of an MZI with L_1=46.3 cm



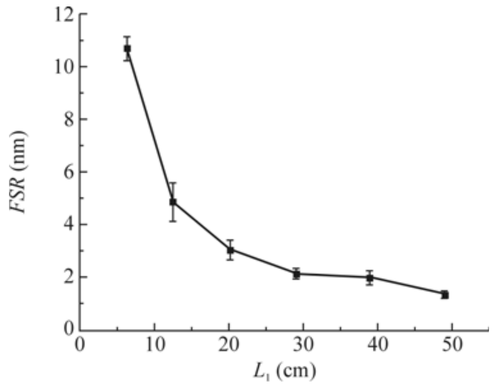
(a) L_1=20.2 cm



(b) L_1=12.5 cm



(c) L_1=6.3 cm



(d) *FSR* versus L_1

Fig.4 Transmission spectra of the MZI with (a) L_1=20.2 cm, (b) L_1=12.5 cm, (c) L_1=6.3 cm; (d) The FSR as a function of L_1 (The zero line does not indicate the real loss characteristic but is defined to be the maximum in the range of 1525–1575 nm.)

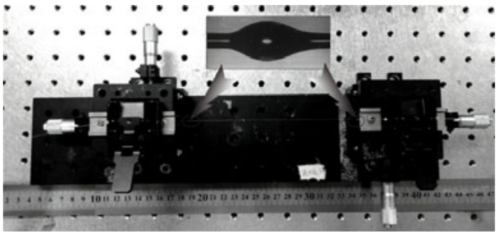
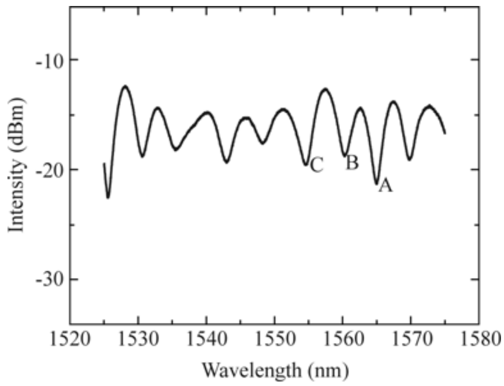
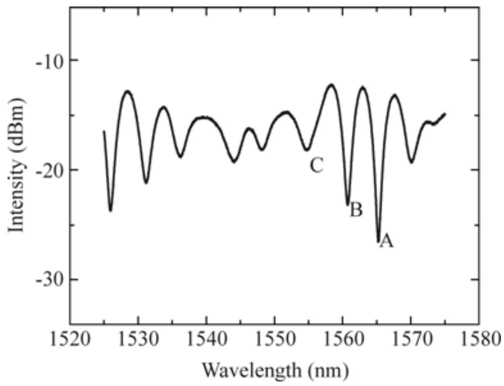


Fig.5 Photo of the device for adjusting elongation

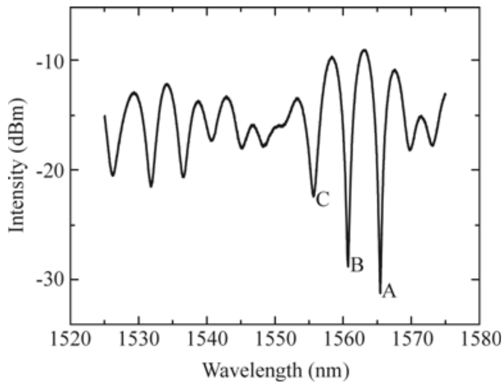
Fig.6 shows the transmission spectra of the MZI with different elongations. In Fig.6, we find out that the extinction ratios of peaks increase with the increase of the elongation. When elongation is equal to zero, the minimum intensity is located at point A. With the increase of elongation, the location of minimum intensity shifts orderly to point B,



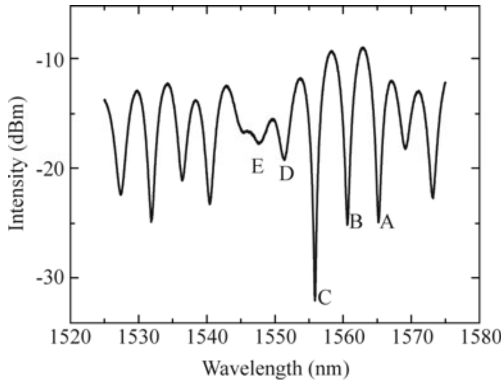
(a) 0.000%



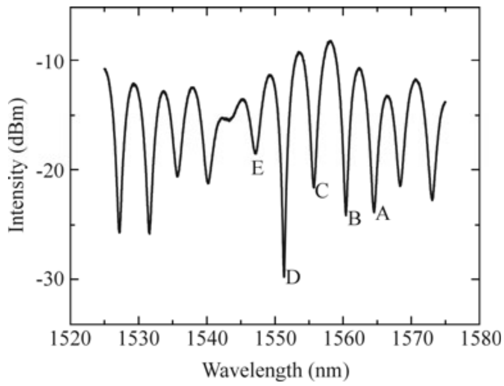
(b) 0.023%



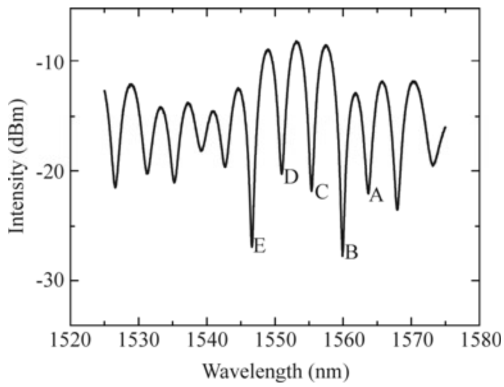
(c) 0.047%



(d) 0.081%



(e) 0.145%



(f) 0.233%

Fig.6 Transmission spectra of the MZI with different elongations, where points A, B, C, D and E indicate the minimum in the corresponding range, respectively

C, D and E. The wavelength range between points A and E is about 20 nm, meanwhile, the point A (the same as points B, C, D and E) shifts in the range of a few nanometers.

When the elongation of MZI is equal to zero, the extinction ratios in the range of points A, B, C, D and E are all less than 10 dB, which can be observed from Fig.7. Then, with the increase of elongation of MZI, the extinction ratios of all the points all increase (higher than 10 dB). The most important result is that the maximum of extinction ratio shifts from point A (or B) to point E.

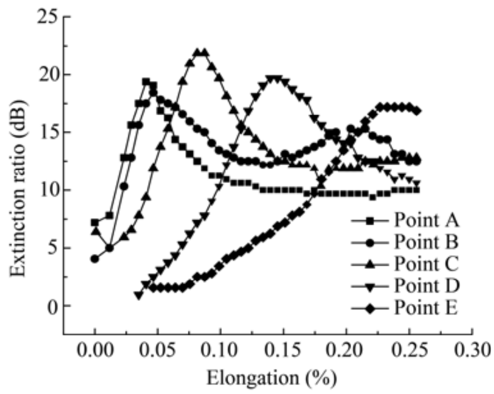


Fig.7 The extinction ratios of points A, B, C, D and E versus elongation of the MZI

In summary, we report an MZI based on two up-tapers on an SMF-28. The maximum extinction ratio is obtained as more than 20 dB. The proposal may be attractive due to a higher extinction ratio can be achieved by improving the parameters of the operated program and the configuration of the up-tapers. It is also found that the increase of the elongation of the MZI leads to the increase of extinction ratio. We get an increse of about 20 dB in our experiment. Meanwhile, the maximum of extinction ratio shifts to the short wavelength in the scope of tens of nanometers while the elongation changes from 0% to 0.23%. The up-tapered configuration is helpful for increasing the strength of the whole MZI. Because of the characteristics of the up-tapered MZI mentioned above, it can be applied in strain sensor or tunable fiber laser systems with less package compared with traditional tapers.

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